

RESEARCH MEMORANDUM

TOOTH-TYPE NOISE-SUPPRESSION DEVICES ON A FULL-SCALE
AXIAL-FLOW TURBOJET ENGINE

By Edmund E. Callaghan, Walton Howes, and Warren North

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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SUMMARY

A study of two jet-noise-suppression devices consisting of teeth projecting into the jet stream was conducted on a current axial-flow turbojet engine. The sound fields obtained with the toothed devices showed a slight reduction in maximum sound pressure level (2 db), compared with the sound field from a standard nozzle. The sound fields of the toothed devices were very similar and (when compared with a standard nozzle) showed a reduction of sound pressure level downstream of the jet with increased levels on the front and side. The total radiated power from the toothed and standard nozzles was very nearly the same (± 1 db). Because of the small reduction in maximum sound pressure level and because the total radiated power in all cases was nearly the same, it was concluded that the toothed devices investigated do not represent a satisfactory solution to the jet-noise problem.

INTRODUCTION

The noise of aircraft operations near densely populated residential areas has become a matter of great concern in recent years, principally because of the large increase in engine power in the last decade, along with increased aircraft operations and the general movement of the population to suburban areas where airports are usually located. Because of the protest against aircraft noise, airline operators have greatly altered their flight patterns into and out of various airports. Such measures are at best temporary, and efforts are being made to reduce the noise at its source. Noise reduction of the reciprocating engine and propeller has been the subject of considerable research, and methods of noise alleviation are suggested in references 1 to 6.

The future operation of jet-propelled transports will present an even more severe noise problem. Jet-engine noises can be categorized generally as (1) internal noises created inside the engine and propagated

outward through the inlet and the tail pipe, and (2) external noises resulting from the mixing of the jet with the surrounding atmosphere. Internal noises, in general, result from flow instabilities and turbulence in the compressor, the combustors, or the turbine. An example of such noises is compressor whine.

External noises caused by the jet are associated with two separate regimes (ref. 7): a subsonic or transonic turbulent mixing regime where no severe shocks exist, and a supersonic overchoked regime wherein the noise results from both turbulent mixing and shock waves. The noise levels are much higher in the supersonic than in the subsonic region, as would be expected, since the passage of turbulence through shock waves results in increased noise levels (ref. 8). Fortunately, with respect to the jet-transport problem, the engine pressure ratios of current and contemplated turbojet engines are not sufficiently high to produce severe shock waves at static sea-level and take-off thrust conditions. In flight at high speeds, such conditions will exist, but as yet insufficient information is available to judge their effects on cabin noise levels.

The general theory of noise created aerodynamically is presented in reference 9. From this general theory has resulted the approximate relation that the total acoustic power radiated from a source (jet) varies approximately as the eighth power of the jet velocity and the square of the jet diameter. The limited experimental evidence to date (refs. 7, 10, and 11) in general supports this result, but there has been as yet no definitive experimental work that can be taken as complete confirmation.

The investigation reported herein was conducted at the NACA Lewis laboratory and represents a preliminary portion of a large program of study of jet noise and means for its suppression. This report describes the results obtained on two full-scale noise-suppression devices suggested by the research of Westley and Lilley (ref. 7). The results presented are concerned with measurements of the sound field in the vicinity of the engine. No attempt is made to assess the possible effects on engine performance of the noise-suppression devices.

BRITISH INVESTIGATIONS

The initial research on the jet noise problem was conducted by the British. An investigation of jet noise and methods for its reduction was undertaken by Westley and Lilley (ref. 7) with a model jet (1-in. diam.), and a brief investigation of full-scale engines was made by Greatrex (ref. 10). Both investigations showed that toothed devices projecting into the jet stream may offer a means of reducing the sound pressure level downstream of the jet. The results given by Greatrex (ref. 10) for several jet engines with production tail pipes are included in figure 1 where the

over-all sound pressure level is plotted as a function of the jet velocity. These data were obtained at a position 30° from the jet axis (downstream of the jet exit) and 60 feet from the engine exit nozzle. The upper curve is for both an Avon engine and a 9000-pound thrust engine; the bottom curve is for a Derwent engine. A single point is also shown for a Nene engine. The increase in sound pressure level with velocity shown in figure 1 corresponds to an increase in sound pressure as the fourth power of the jet velocity. Since the sound power varies as the square of the sound pressure, the variation of sound pressure level with velocity (fig. 1) corresponds to an eighth-power relation of velocity to sound power. The results shown are therefore in good agreement with the values predicted in reference 9.

The separation of the data into separate curves is due somewhat to the nozzle-diameter variation among the various engines; that is, over-all sound pressure varies directly with exit diameter (ref. 11). The nozzle-diameter variation, however, accounts for only about 2 decibels of the total spread of 7 decibels. The apparently unaccountable remaining variation of about 5 decibels may be due to a difference in measuring techniques but is more likely due to the difference in initial turbulence of the various jets (ref. 11).

Although the available data on jet noise are quite limited, it is interesting to compare the results for the full-scale Derwent engine (exit diam., 16 in.) with the results for a 1-inch-diameter model jet given in reference 7. The data of reference 7 show that at a total-to-static-pressure ratio of 1.9, an angle 30° from the jet axis, and a distance of 60 feet from the jet exit, the over-all sound pressure level is approximately 89 decibels. If it is assumed that the jet total temperature was 80°F (these were cold-air tests), then the jet velocity corresponding to this pressure ratio and temperature is 1040 feet per second. The correction for diameter variation given theoretically by Lighthill (ref. 9) and confirmed experimentally by reference 11 indicates that the over-all sound pressure varies directly with the diameter, that is, the sound power varies as the square of the diameter. A correction of 24 decibels must be added to the model test results (1-in. diam.) to make them comparable to the Derwent engine data of figure 1. The model test data, corrected to a diameter of 16 inches at 1040 feet per second (113 db), falls just below the Derwent curve as indicated on figure 1. The agreement is remarkable considering the widely different conditions between the two investigations. In view of the good agreement between the engine and model data, it may be tentatively hypothesized that the principal source of jet-engine noise is the external noise resulting from the turbulent mixing of the jet with the surrounding medium. Additional evidence in support of this hypothesis can be obtained from reference 10, which reports experiments on the same engine with and without afterburning. The azimuth angle and distance for these tests are not available, but the data for both afterburning and nonafterburning operation yield a single curve of sound pressure level as a function of velocity (fig. 1). This

curve falls between and has the same slope as the Derwent and Avon curves. The limited information to date therefore indicates that the principal noise source is jet mixing, and hence to change the noise source the turbulent mixing process itself must be changed. This means in reality that the jet velocity, velocity distribution, or jet spreading characteristics must be altered to obtain changes in the sound field. At the present time, the relative importance of each of these parameters can be determined by experiment only. Preliminary work along this line was conducted by Westley and Lilley (ref. 7); a number of toothed devices projecting into the jet stream for the purpose of reducing the rate of shear were studied, and several configurations were obtained which reduced the over-all noise level along the azimuth line of maximum sound pressure level (30° from the jet axis).

A limited investigation of some of these toothed devices on an engine installation is reported in reference 10, but again, as for reference 7, the entire sound field is not given. It is the purpose of this report to present preliminary measurements of the sound field around a full-scale engine fitted with the two most promising devices reported in reference 7.

APPARATUS AND PROCEDURE

The engine used in this investigation was mounted beneath the wing of a C-82 aircraft as shown in figure 2. The area where the tests were conducted is unobstructed rearward and to the sides of the jet for over $1/2$ mile. The nearest reflecting surface other than the aircraft surfaces was located approximately 600 feet in front of the aircraft. Measurements of the over-all sound pressure level were made approximately 6 feet above ground level at 15° intervals from the jet axis and at distances from the jet exit of 50, 100, and 200 feet as shown in figure 3. Sound-pressure-level measurements were made with both a General Radio Company Type 1555-A Sound-Survey Meter and a Type 1551-A Sound-Level Meter; both instruments were carefully calibrated against a reference sound generator. The sound pressure level measured by these meters is referred to the standard reference pressure of 0.0002 dyne per square centimeter. The microphones of both sound meters were shielded by a windscreen to reduce wind noise.

The jet engine used in this investigation was a current 12-stage axial-flow engine with a rated sea-level static thrust of 5000 pounds at an engine speed of 7950 rpm and a turbine-outlet temperature of 690° C. The engine was operated without a tail pipe because the blocking effect of the toothed devices provided sufficient restriction of the exit area to obtain rated tail-pipe temperature at rated engine speed. In order to obtain comparative data from a nozzle without teeth, it was necessary to clamp a nozzle ring with trim tabs to the tailcone as shown in figure 4. This installation permitted operation of the engine at rated tail-pipe temperature and engine speed and is hereinafter referred to as the standard nozzle.

The two sets of toothed devices investigated (fig. 5) are scaled-up versions of those given in reference 7. The noise-suppression device shown in figure 5(a) consists of six teeth, each $1/4$ exit diameter on a side. Alternate teeth project into the jet at an angle of 30° to the jet axis, and the remaining teeth are parallel to the jet. The other toothed device investigated (fig. 5(b)) consists of 12 rectangular teeth. Six alternate teeth, $3/8$ diameter long and $1/8$ diameter wide, project into the jet at an angle of 30° . The remaining teeth, $1/4$ diameter long by $1/8$ diameter wide, are parallel to the jet.

The sound field was surveyed by obtaining measurements of sound pressure level at each of the stations shown in figure 3 at constant values of tail-pipe temperature and engine speed. These measurements required approximately 7 minutes. The sound field was surveyed with the standard nozzle at 80, 90, and 100 percent of rated engine speed and with the toothed nozzles at only rated engine speed and rated tail-pipe temperature.

RESULTS AND DISCUSSION

Although the field in which the aircraft test bed is located is unobstructed, the aircraft itself represents a serious obstacle in the sound field. The results presented can at least be judged on a comparative basis, and because of the engine location on the aircraft, the sound field rearward should not be very different from that obtained with an engine alone. For purposes of comparing the various nozzles, the test setup should be adequate and the comparative answers valid.

Measurements along the various azimuth lines were plotted as a function of the distance from the jet exit, and it was found that the sound pressure level varied in accordance with the inverse square law for free-field measurements. At the closest point (50 ft) from the jet, the sound pressure levels were generally 1 to 2 decibels above the theoretical curve, indicating that at points closer to the jet considerable deviations from the square law might be obtained. In the present investigation no near-field measurements were made. At constant jet velocity, equal sound pressure levels were obtained with and without the exit area trimmers shown in figure 4.

The variation of sound pressure level, with the standard nozzle, as a function of jet velocity for the 30° azimuth line at a distance 60 feet from the jet exit is shown in figure 1. The sound pressure level at a distance of 60 feet was obtained from the plots of sound pressure level against distance as previously described. The data obtained are in good agreement with those presented in reference 10. The slope of the curve is the same as for the other engines presented, and the curve falls just slightly above the curve for the Derwent engine and considerably below that for the Avon engine as would be expected from a comparison of the static thrust of the three engines.

The sound pressure fields for both the standard nozzle and the six-toothed nozzle at rated engine speed and rated tail-pipe temperature are shown in figure 6(a). As a matter of record, the meteorological conditions for each sound survey were recorded and are presented in figure 6. No significant trends with wind velocity were apparent in the data, probably because no tests were made at wind velocities higher than 16 miles per hour. These data have been corrected to a distance of 100 diameters from the jet nozzle by using the previously described curves of sound pressure level against distance (100 diameters is a standard distance proposed for presentation of jet sound pressure data). This method of plotting such data was developed in reference 11 wherein it was shown that sound pressure varies directly with diameter and inversely with distance. The results presented for the standard nozzle (fig. 6) show that the highest noise level is obtained at an azimuth angle between 30° and 40° from the jet axis downstream of the jet exit. The effect of the six-toothed nozzle is to move the point of maximum intensity to an azimuth angle of approximately 60° and to lower the maximum value by approximately 2 decibels. A comparison of the two curves shows that the toothed nozzle lowers the noise level downstream of the jet but increases it on the sides and front such that the total radiated power (assuming the sound field symmetrical about the jet center line) from both nozzles is within 1 decibel.

Rotational symmetry of the sound field about the jet axis was investigated by rotating the six-toothed nozzle two 30° increments. The data obtained in the two rotated positions yielded curves identical to that of figure 6.

The results obtained with the 12-toothed nozzle are shown in figure 6(b) with the standard nozzle given as a reference. The results obtained are very similar to those previously discussed for the six-toothed nozzle. The point of maximum noise intensity occurs at an azimuth angle of approximately 60° . The maximum noise level with a toothed nozzle is approximately 2 decibels less than the maximum noise level with the standard nozzle; again, as for the six-toothed nozzle, the noise level downstream of the jet is decreased but is increased on the front and sides such that the total noise power radiated is within 1 decibel of that radiated from the standard nozzle.

The shifting of the sound field by means of teeth alleviates the noise problem rearward but causes no appreciable changes in the maximum noise level during take-off as shown in figure 7. The noise level at a point on the ground caused by the standard and six-toothed nozzles has been calculated from the results presented in figure 6 for a single jet passing directly overhead at an altitude of 200 feet, a velocity of 300 feet per second, and NACA standard conditions. The origin of the time scale ($t=0$) corresponds to a sound pressure level at the observer (caused by the standard nozzle) which is 10 decibels above typical airport background level (67.5 db). For both cases shown, the sound pressure level increases rapidly with time to the maximum value. The maximum noise levels in both cases are almost identical, and even though the noise from the

toothed nozzles falls off more rapidly than the noise from the standard nozzle, it is questionable whether any real gain in reducing the nuisance value has been achieved.

From the results presented in figures 6 and 7, it is apparent that the noise reduction obtainable with toothed nozzles is quite small. The results given in reference 10 are somewhat deceiving because data are presented at the 30° azimuth angle only and it is at this point that the greatest noise reduction due to teeth is obtained. This reduction is primarily due to the shifting of the maximum sound level to the 60° azimuth line.

The preliminary data obtained in the present investigation show that the noise suppression obtainable with the toothed devices studied is small at best. Since the over-all radiated power is nearly the same with both the toothed and standard nozzles, it would appear that toothed nozzles are not a satisfactory solution to the jet-noise problem.

SUMMARY OF RESULTS

As a preliminary portion of a program for studying jet noise and its suppression, two configurations of noise-suppression devices suggested by the research of Westley and Lilley were tested on a current axial-flow turbojet engine. The results showed that a slight reduction (2 db) in maximum noise level was obtained with the toothed nozzles investigated. The sound fields obtained with both toothed devices were very similar and when compared with a standard nozzle showed a decrease in sound pressure level downstream of the jet with increased levels on the side and front. The total radiated power from both toothed-nozzle configurations was within 1 decibel of the standard nozzle. It was concluded, therefore, that no appreciable reduction in over-all nuisance value was obtainable with the toothed nozzles investigated, and it would appear that the teeth do not represent a satisfactory solution to the jet-noise problem.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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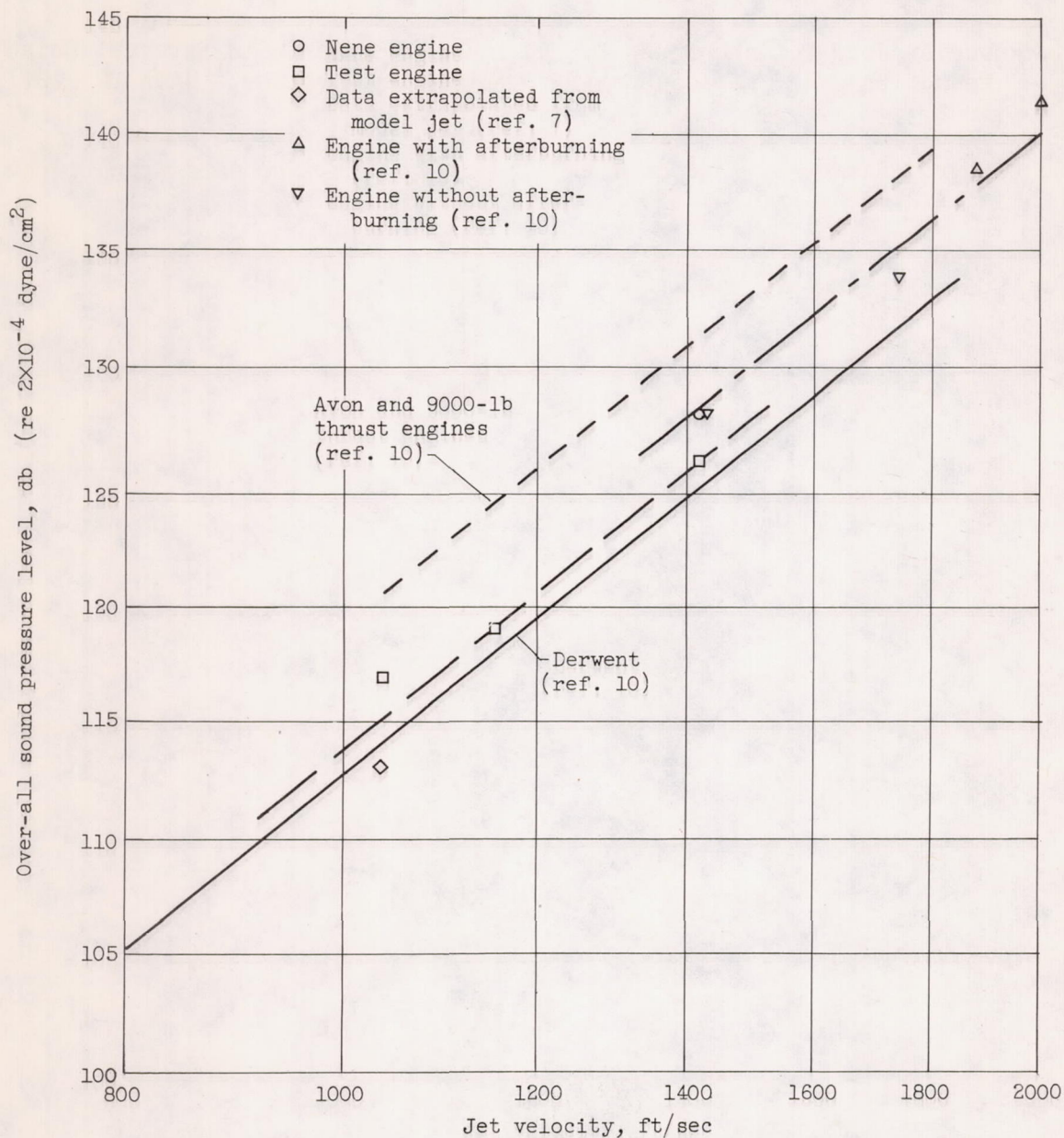


Figure 1. - Variation of over-all sound pressure level as a function of jet velocity for several different jet engines at a position 30° from the jet axis (downstream of jet exit) and 60 feet from jet exit. (The azimuth angle and distance are not available for the afterburning and nonafterburning operation.)

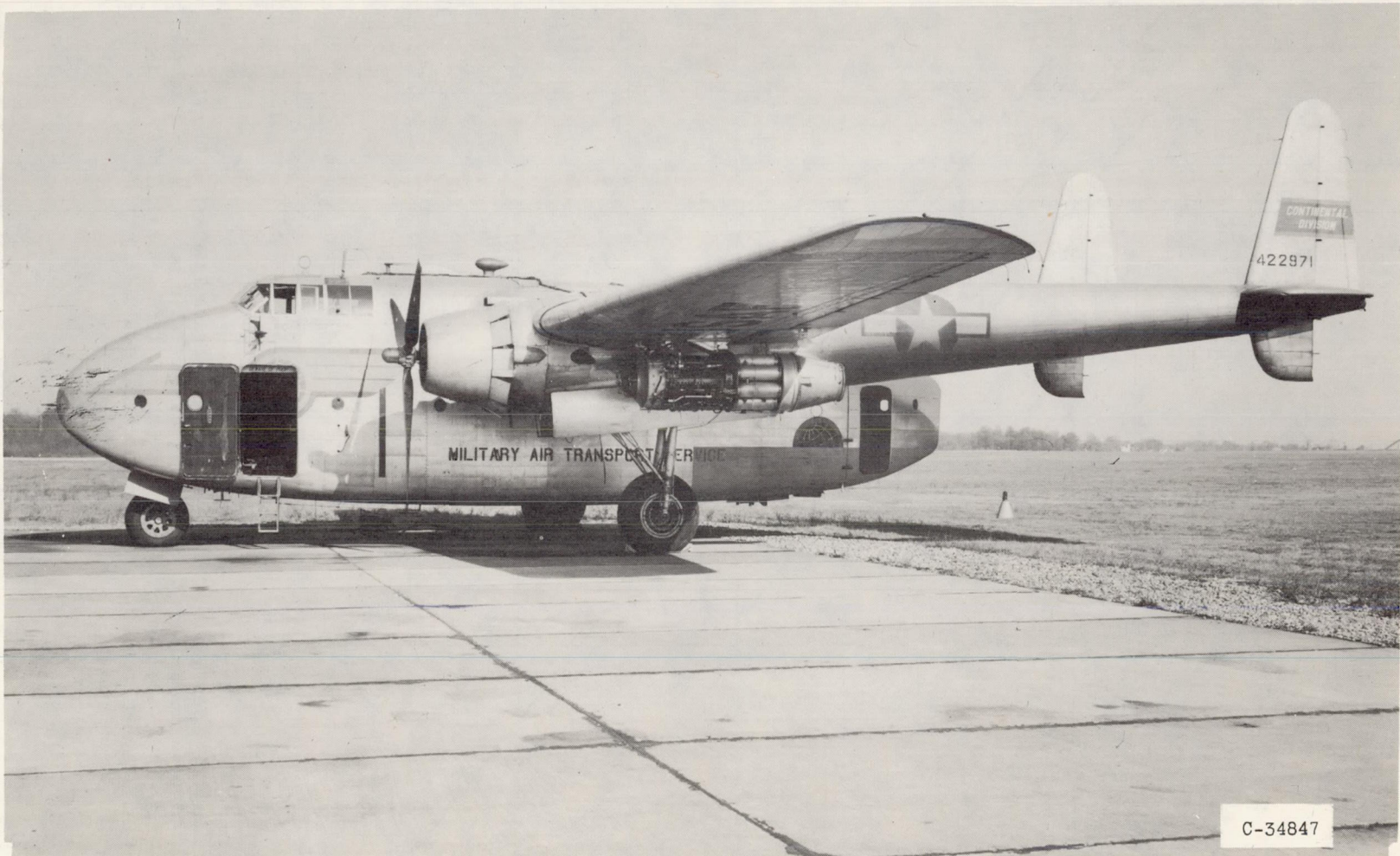


Figure 2. - Location of test engine beneath wing of cargo-type airplane.

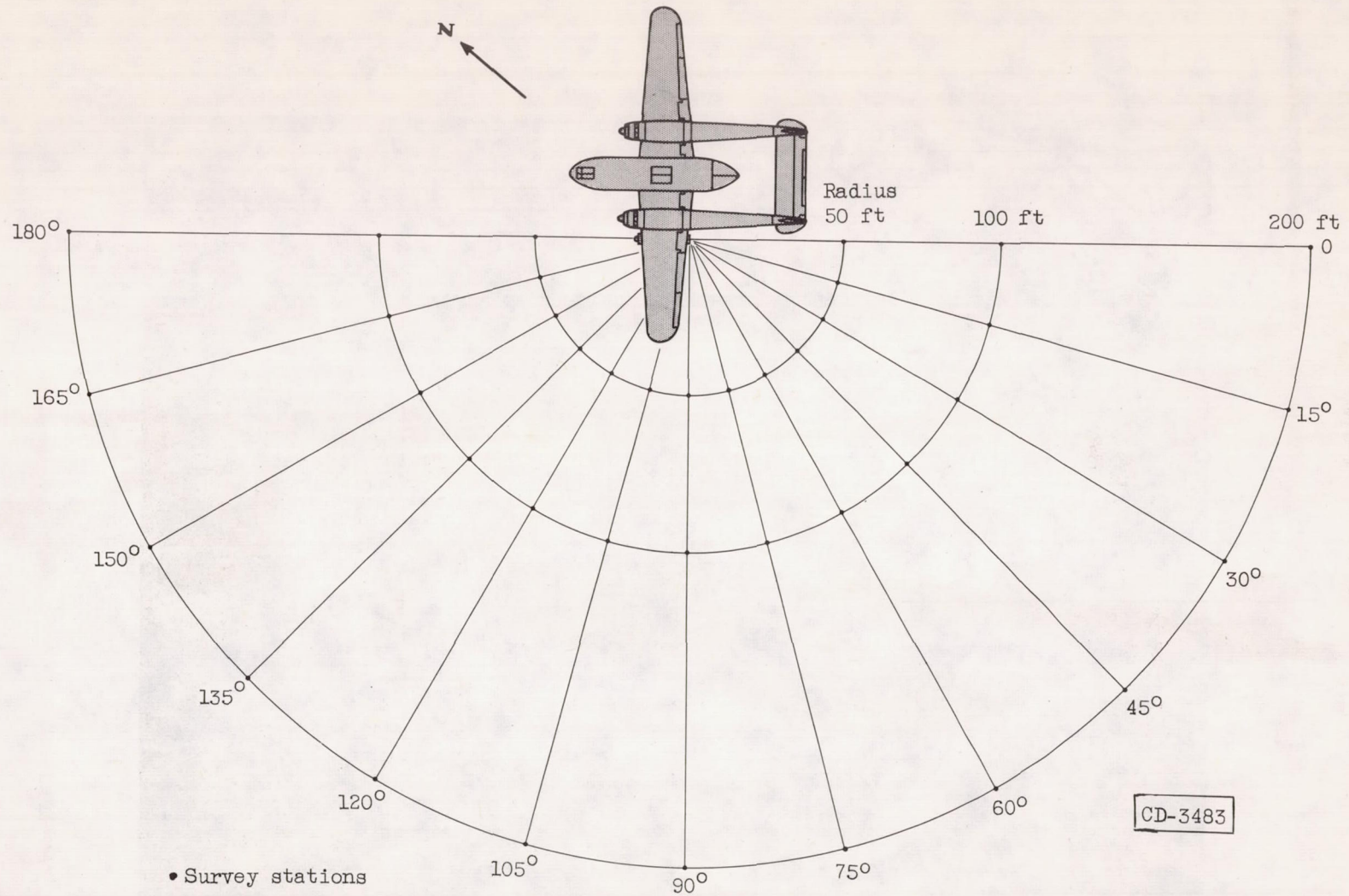


Figure 3. - Location of survey stations in sound field around aircraft test bed.

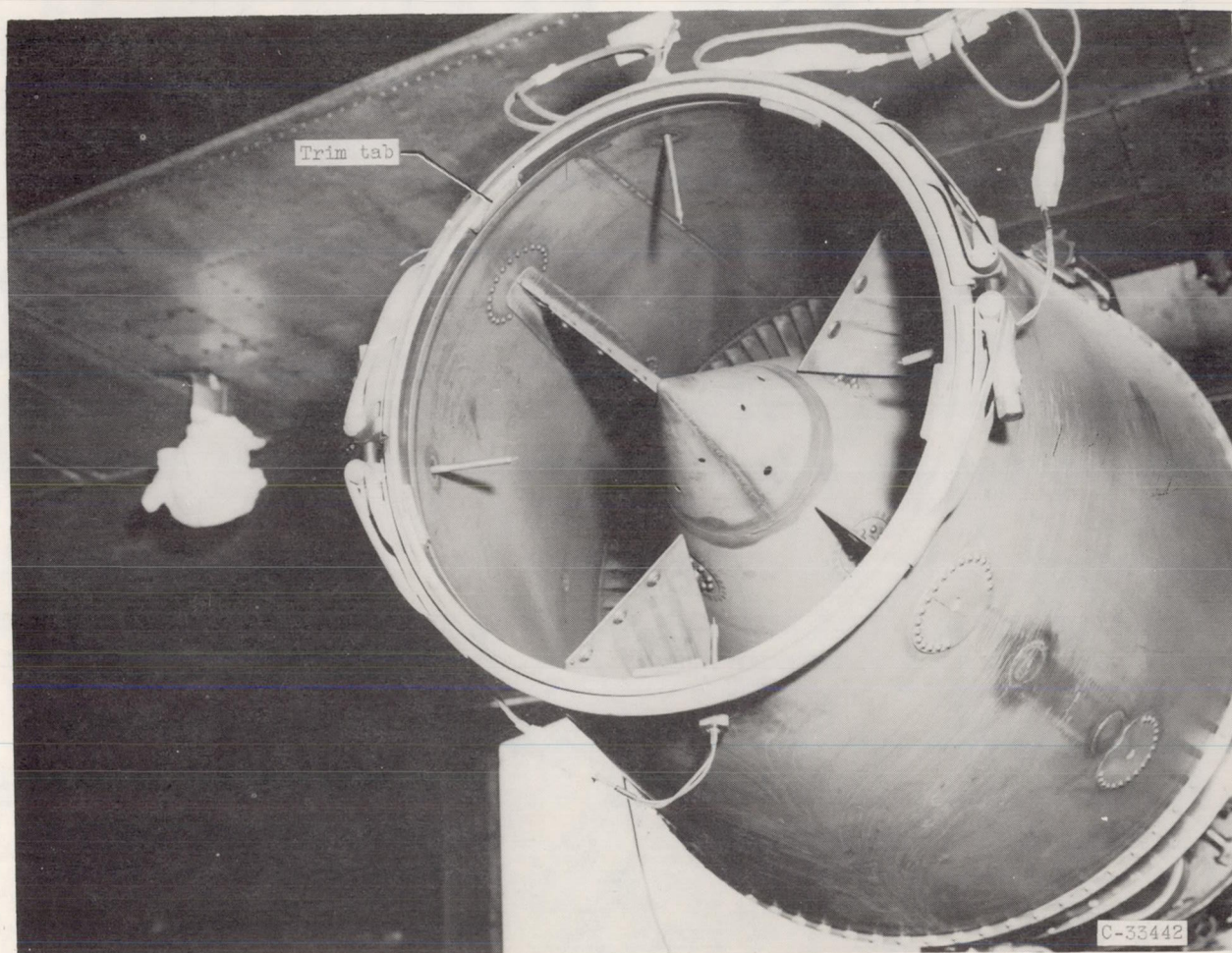
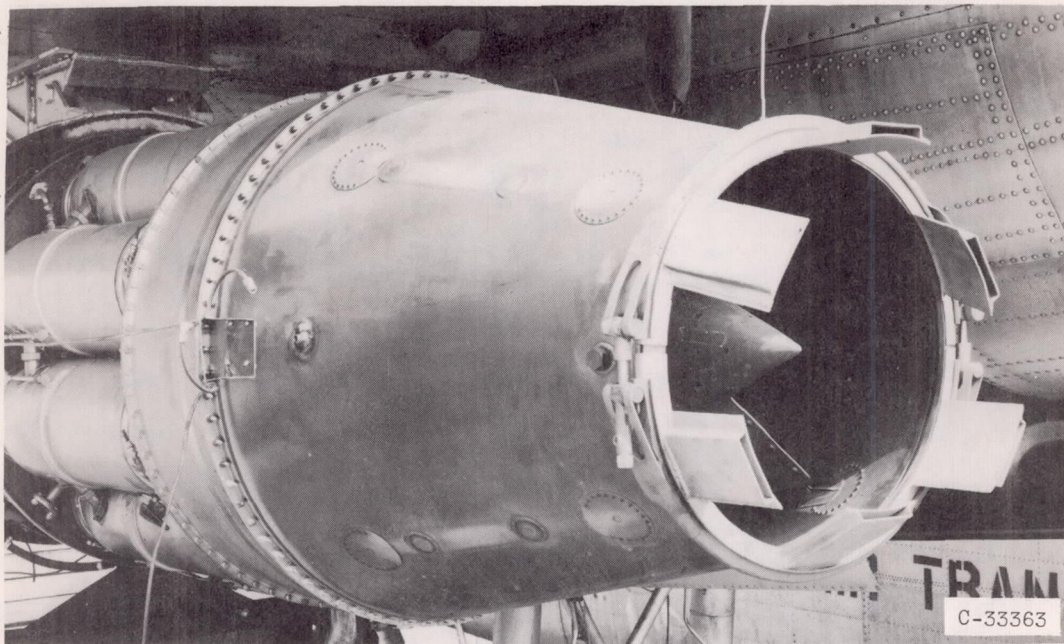
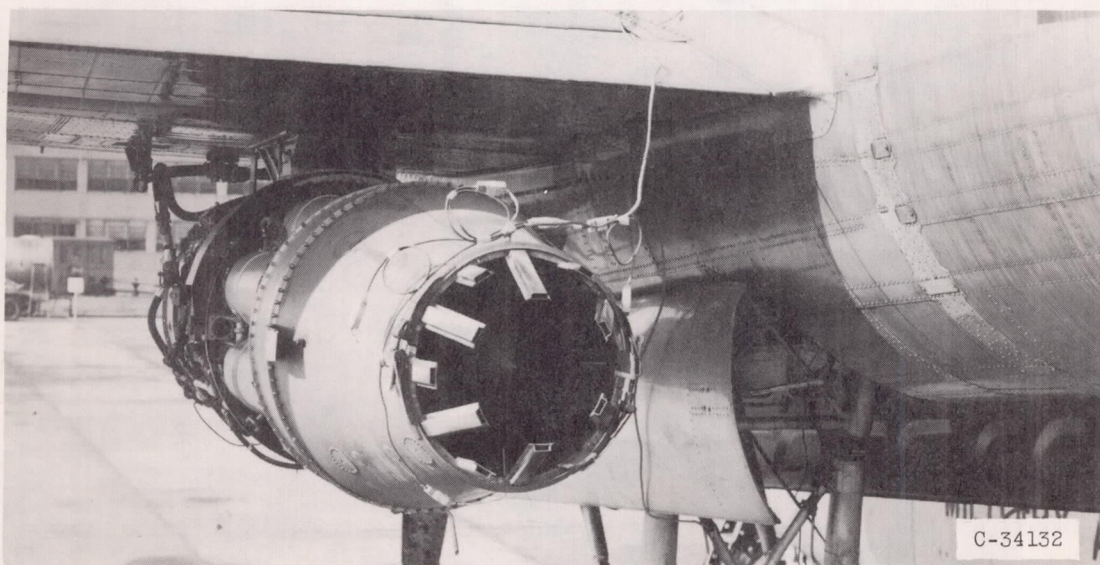


Figure 4. - Jet-engine exhaust nozzle with trim tabs (standard nozzle configuration) used as noise standard for comparison with other exit nozzles.



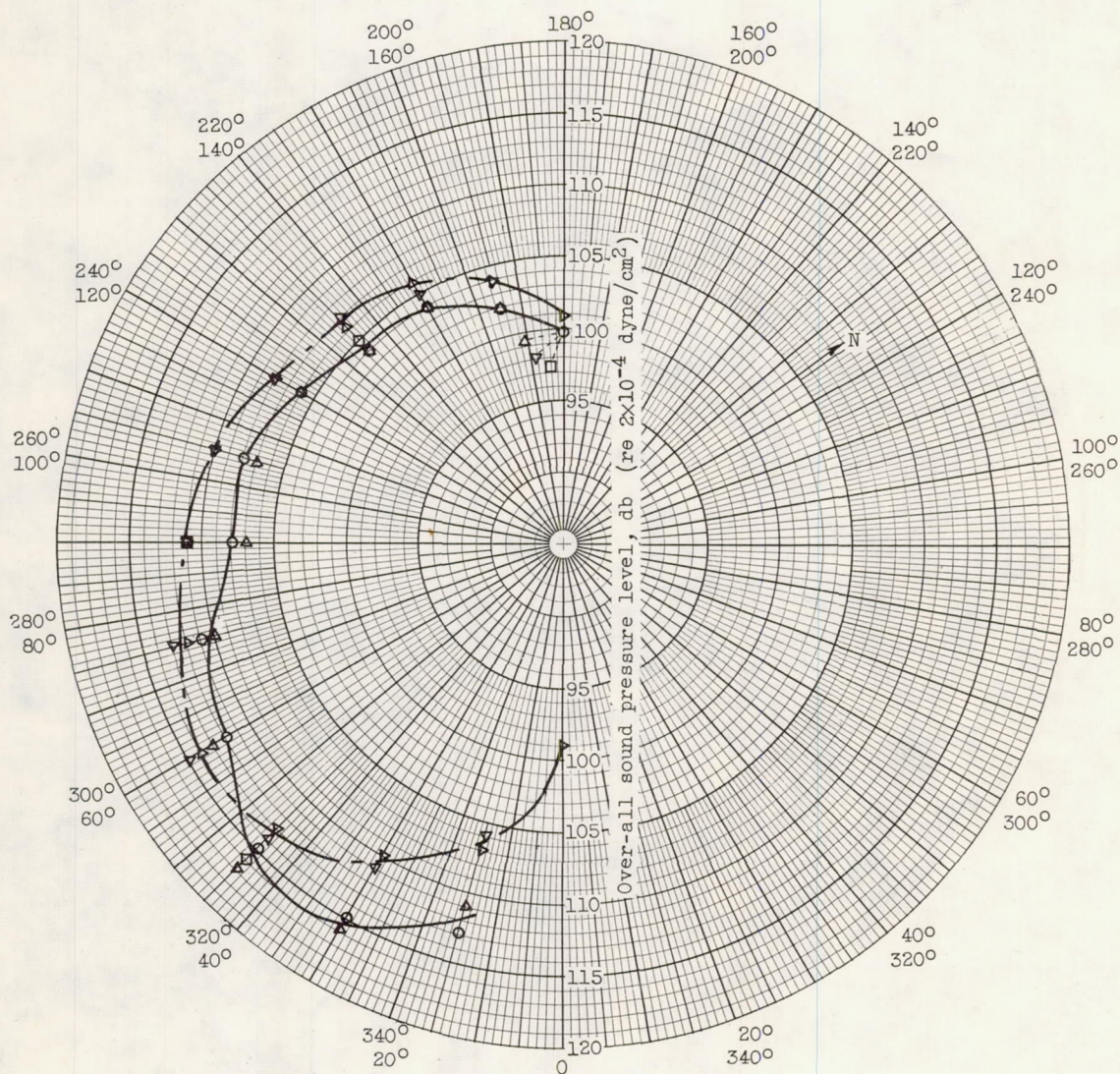
(a) Six-toothed nozzle. Each tooth $1/4$ exit diameter on a side; three teeth projecting into jet stream at 30° , three teeth parallel to jet stream.



(b) Twelve-toothed nozzle. Six teeth $1/8$ diameter wide and $3/8$ diameter long projecting into jet stream at a 30° angle, six teeth $1/8$ diameter wide and $1/4$ diameter long parallel to jet stream.

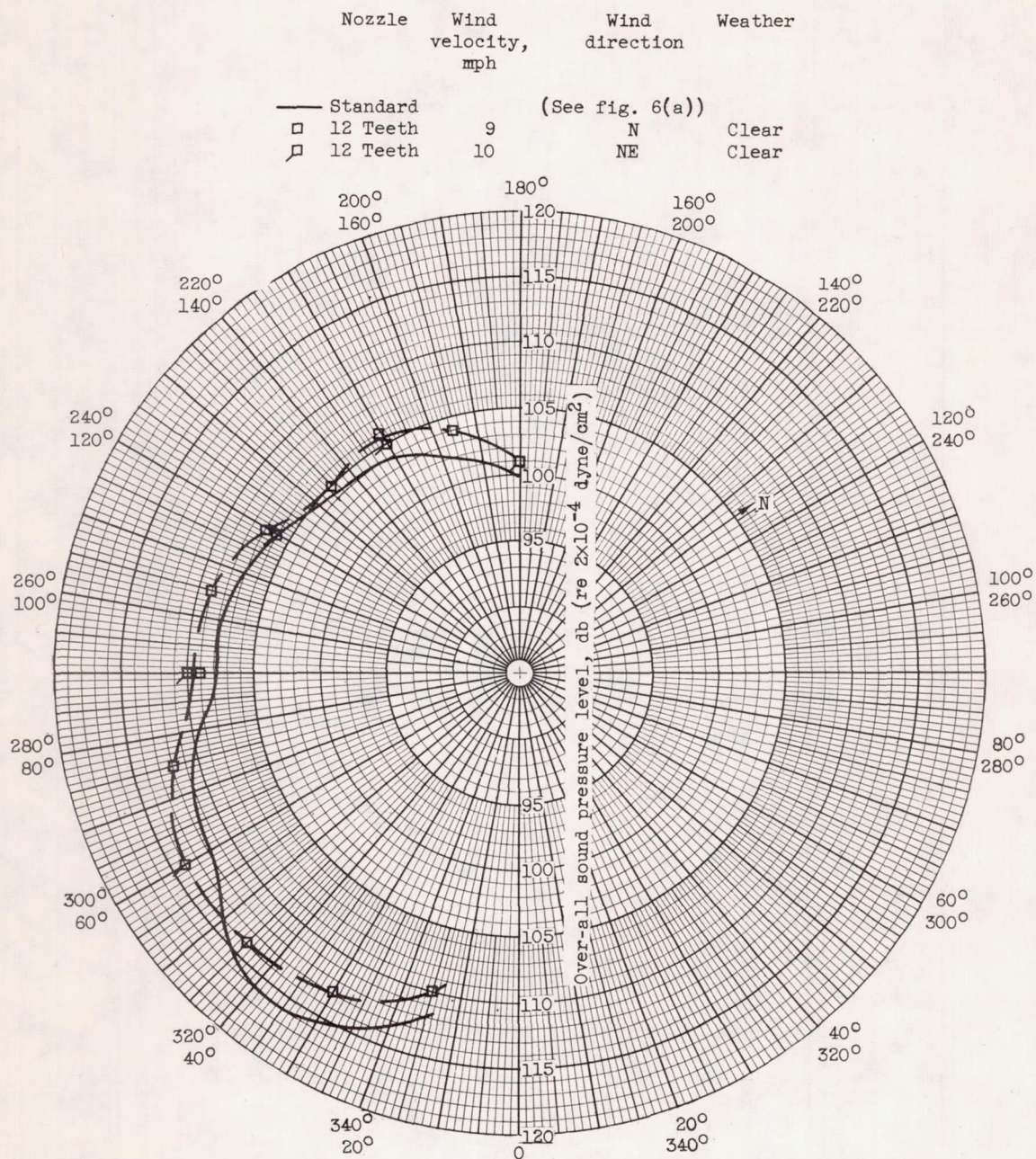
Figure 5. - Toothed nozzles with large projections into jet stream.

Nozzle	Wind velocity, mph	Wind direction	Weather
○ Standard	8 to 10	N	Scattered clouds
□ Standard	8	W	Clear
△ Standard	16	NW	Clear
▽ Six teeth	8	N	Clear
▷ Six teeth	4	NW	Clear



(a) Standard and six-toothed nozzles.

Figure 6. - Polar diagram of noise field. Sound pressure levels are corrected to a distance of 100 nozzle diameters from jet exit.



(b) Standard and 12-toothed nozzles.

Figure 6. - Concluded. Polar diagram of noise field. Sound pressure levels are corrected to a distance of 100 nozzle diameters from jet exit.

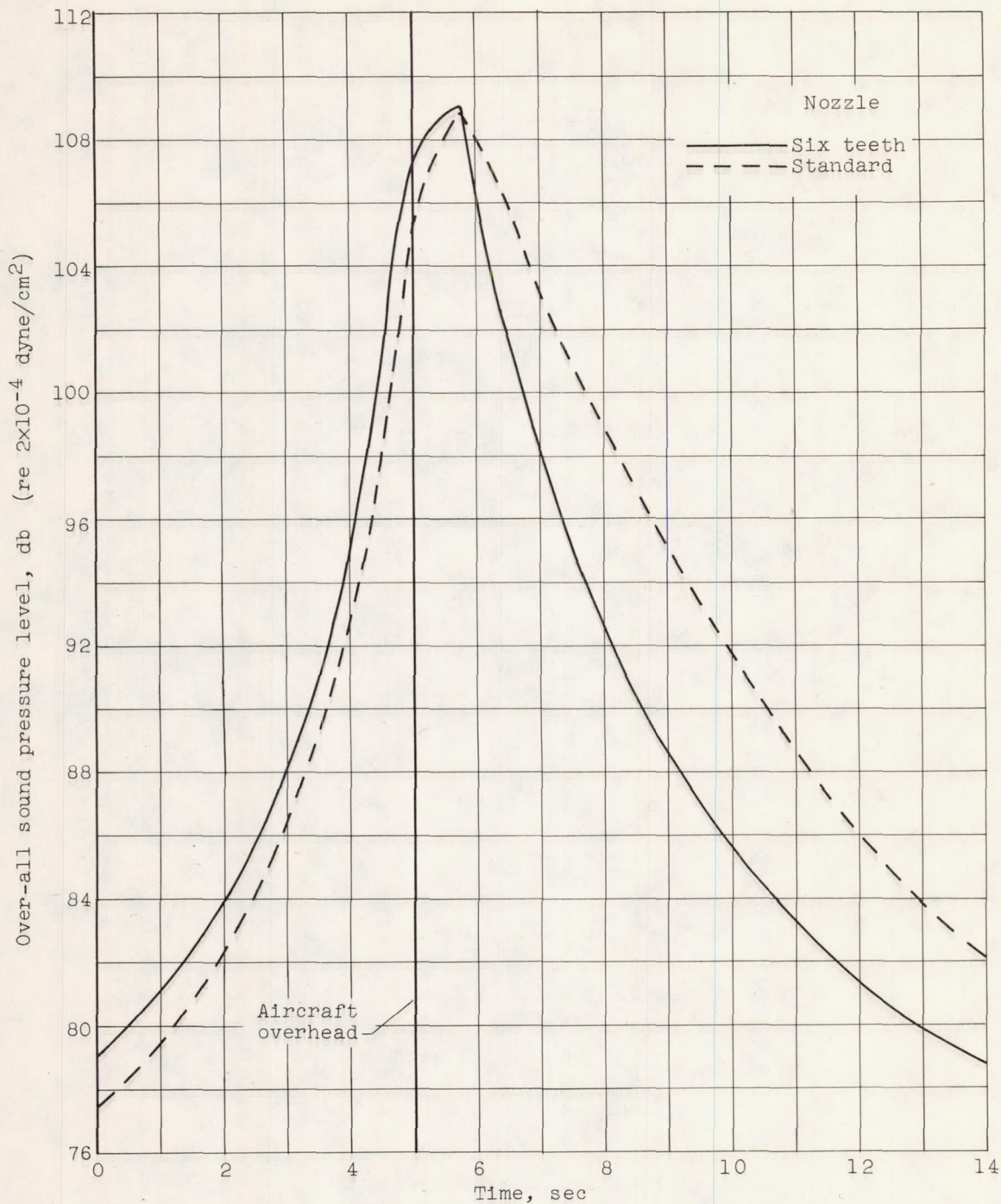


Figure 7. - Calculated noise level heard by stationary observer for single jet passing directly overhead at altitude of 200 feet and velocity of 300 feet per second.